SLAC-PUB-618
June 1969
(TH) and (EXP)

Total and Partial Photoproduction Cross Sections at 1.44, 2.8 and 4.7 GeV +)

J. Ballam, G.B. Chadwick, R. Gearhart,
Z.G.T. Guiragossián, P.R. Klein, A. Levy*), M. Menke,
J.J. Murray, P. Seyboth**), G. Wolf***)

Stanford Linear Accelerator Center
Stanford University, Stanford, California

C.K. Sinclair

Tufts University, Medford, Massachusetts

H.H. Bingham, W.B. Fretter, K.C. Moffeit,
W.J. Podolsky, M.S. Rabin, A.H. Rosenfeld, R. Windmolders‡)

Department of Physics and Lawrence
Radiation Laboratory, University of California, Berkeley, California

(submitted to Phys. Rev. Letters)

+) Work supported in part by the U.S. Atomic Energy Commission and the National Science Foundation.

*) On leave from Tel Aviv University, Tel Aviv, Israel.

**) On leave from Max-Planck Institut für Physik und Astrophysik, Munich, Germany

***) On Leave from DESY, Hamburg, Germany.

‡) Visitor from Laboratoire Interuniversitaire des Hautes Energies, Brussels, Belgium.

Abstract

A nearly monochromatic high energy photon beam produced by Compton backscattering of ruby laser light has been used to study photoproduction in a hydrogen bubble chamber. The total hadronic γp cross sections at 1.44, 2.8 and 4.7 GeV are found to be 145.1 ± 5.7 μb, 131.3 ± 4.3 μb and 124.2 ± 3.9 μb, respectively. Partial cross sections are presented also.

In 1963, R. Milburn[1] concurrently with Arutyunian et al.[2] pointed out that Compton backscattering of an intense polarized light beam by high energy electrons would produce useful yields of monoenergetic, polarized photons. Such a beam has been realized at SLAC[3] and used together with the 82 inch LRL-SLAC Hydrogen Bubble Chamber for a study of γp interactions with linearly polarized photons. About 800,000 pictures have been taken at photon energies of 1.44, 2.8 and 4.7 GeV, 10 percent of which have been used for the present study. Because the energy spread is small and because the bubble chamber permits a clear separation of electromagnetic and hadronic interactions, the exposures allow a straightforward measurement of the total hadronic γp cross section. Thus this measurement is free of the usual background and detection biases caused by the 150 times more copious pair production.

Beam

The beam results from Compton backscattering of light by high energy electrons. This is a two body process; hence for given incident photon and electron energies k_i and E, the energy k of the scattered photon depends only on the laboratory angle θ as measured with respect to the incident electron beam:

$$k = \frac{E(1 - a)}{1 + a(\gamma\theta)^2} \quad , \theta \ll 1 \tag{1}$$

where m = electron mass, $\gamma = \frac{E}{m}$ and $a = \frac{1}{1 + 4\gamma \frac{k_i}{m}}$.

To limit the scattered photon energies to the top ten percent of the Compton spectrum at our energies requires angular definition of the order of 10^{-5} radians about $\theta = 0^{\circ}$ for both the incident electron and the backscattered photon beam. A special feature of the Compton process is that if the incident light is polarized, the high energy part of the Compton spectrum is almost completely polarized in the same way.

Figure 1a shows the beam schematic layout. Some 10^{11} electrons in a 1 μ pulse pass through the 5 meter long interaction region. The electron beam is a few millimeters in diameter with about 10^{-5} radians divergence. The linearly polarized light beam is generated by a Q-switched ruby laser ($\lambda = 6934$Å, $k_i = 1.786$ eV, maximum output = 2 Joule, pulse length = 50 ns). The polarization mode can be changed from pulse to pulse by a set of $\lambda/4$ and $\lambda/2$ plates. The two beams clash at a relative angle of 3 mrad in the interaction region. The accepted range of scattered photon angles is defined by a 2 mm diameter hole in the final collimator 100 meter downstream of the interaction region. Scintillators embedded in this collimator are used to control the beam steering to 10^{-6} radians. The optimal flux for the analysis of the photographs turned out to be 100 photons per pulse; actually, several hundred were obtainable at the higher energies.

In Fig. 1b-d, the pair energy spectra are shown for the three different energies. In addition to the peak there is a small tail (of a few percent) extending towards low energies. Also shown in Fig. 1b-d are the distributions of the photon energy obtained from events which satisfy a 3 constraint fit to the reaction $\gamma p \rightarrow p\pi^+\pi^-$ and provide a more accurate measurement of the photon energy than do the pairs. Table Ia gives the full width at half maximum of these distributions. The energy determination was checked to 0.2 percent by measuring K^0 decays in the chamber.

Scanning and Measuring

Film was taken at the energies shown in Table Ia. For the total cross section measurement, film with low photon flux was selected. All pictures were independently scanned twice and discrepancies were resolved in a third pass. The combined double-scan efficiency, ϵ, was better than 99 percent for all topologies including e^+e^- pairs except that events with one charged particle had ϵ = 94-97 percent. The scanning efficiencies were checked by scanning part of the film a third time. The photon flux was determined by counting the number of e^+e^- pairs produced in the fiducial volume. The events were measured in order to make sure that the event vertex was located in the beam volume. This volume is well defined because the diameter of the photon beam is less than 3 mm in the chamber. Geometrical reconstruction and kinematical analysis were done using the programs TVGP and SQUAW.

Results

The photoproduction cross section is obtained from the number of events, N_{ev} and the number of e^+e^- pairs, N_{pair} produced in the same chamber volume using the known[4] e^+e^- pair production cross section

σ_{pair}:

$$\sigma_{\gamma p \to hadrons} = \frac{N_{ev}}{N_{pair}} \sigma_{pair} \qquad (2)$$

In Table Ia, b the relevant numbers such as the number of frames scanned and the events found in the various topologies are summarized together with the corrections applied. The low-energy correction removes events produced by photons in the low energy tail. For photon energies below 1 GeV, we used the published cross sections on single[5] and multiple[4] pion production. For energies above 1 GeV, the cross section values measured in this experiment were interpolated. The uncertainties in the cross sections from the low energy photon flux contribute errors of the order of 1.0 - 1.9 μb to the total cross section errors. The loss of events of the type $\gamma p \to p\pi^+\pi^-$ produced at very small momentum transfers to the proton was found to be negligible. The errors given for the cross sections include the statistical uncertainty in the number of events and in the photon flux, the uncertainties in the pair production cross section and in the corrections for low energy photons.

In Fig. 2 the total hadronic γp cross section as measured in this experiment is shown as a function of the photon energy together with the results of previous experiments.[6][7] The cross section values of reference 6 are lower than ours at 2.8 and 4.7 GeV. Our values are in agreement with the preliminary results of a counter measurement[8] and of an inelastic electron-proton scattering experiment.[9]

In the framework of the Vector Dominance Model, the total γp cross section can be related to the forward cross sections for photoproduction of ρ^{0}, ω and φ. Using the assumptions of reference 10, our measurements at 2.8 and 4.7 GeV lead to $\gamma_{\rho}^{2}/4\pi = 0.4 \pm 0.05$ for the square of the γ - ρ coupling constant.

Table Ib presents a breakdown of the total photoproduction cross sections into contributions from various topologies. The contribution from reactions with one charged outgoing particle decreases rapidly between 1.4 and 4.7 GeV. The dominant topology is that with three charged outgoing particles. However, with increasing photon energy reactions with higher multiplicities gain importance. (See also references 4, 7, 11, and 12.) In this respect, photoproduction behaves in the same way as πN, KN, or NN interactions.

Acknowledgements

This experiment required the help of many people. We gratefully acknowledge the contributions of T. B. Cochran in the design stages; R. Vetterlein, W. Graves, and the SLAC RAD group in construction of the beam; the accelerator and DAB operation groups for great cooperation in running the beam; R. Watt and the bubble chamber operators for the exposure; W. Hendricks, M. Tartar, D. Chapman, and our scanning and measuring personnel for remarkable diligence.

References

1. R.H. Milburn, Phys. Rev. Letters, 10, 75 (1963); see also R.H. Milburn, SLAC-Report No. 41 (1965).
2. F.R. Arutyunian, I.I. Goldman, and V.A. Tumanian, Zh. Eksperim. Teor. Fiz. 45, 312 (1963); Soviet Physics JETP 18, 218 (1964). F.R. Arutyunian and V.A. Tumanian, Phys. Letters 4, 176 (1963).
3. J.J. Murray and P. Klein, SLAC-TN 67-19 (1967).
4. Aachen-Berlin-Bonn-Hamburg-Heidelberg-München Collaboration Phys. Rev. 175, 1669 (1968). In this reference the various corrections to the pair production cross section are discussed. The pair production cross section is expected to be correct to within one percent above 0.3 GeV.
5. J.T. Beale, S.D. Ecklund, and R.L. Walker, California Institute of Technology, Report No. CTSL-42 (1966).
6. Aachen-Berlin-Bonn-Hamburg-Heidelberg-München Collaboration, Phys. Letters 27B, 54 (1968).
7. J. Ballam, G.B. Chadwick, Z.G.T. Guiragossián, P. Klein, A. Levy, M. Menke, E. Pickup, T.H. Tan, P. Seyboth, and G. Wolf, Phys. Rev. Letters 21, 1541 (1968).
8. D.O. Caldwell, V.B. Elings. W.P. Hesse, R.J. Morrison, F.V. Murphy, B.W. Worster, and D. Yount, Bull. Am. Phys. Soc. 14,518 (1969).
9. E.D. Bloom, R.L. Cottrell, D.H. Coward, H. DeStaebler, Jr., J. Drees, G. Miller, L.W. Mo, R.E. Taylor, J. I. Friedman, G.C. Hartmann,

and H. W. Kendall, Bull. Am. Phys. Soc. 14, 518 (1969).

10. Z. G. T. Guiragossián and A. Levy, Report No. SLAC-PUB 535, and Nucl. Phys., to be published; contains references for Vector-Dominance Model.

11. Cambridge Bubble Chamber Group, Phys. Rev. 169, 1081 (1968).

12. Y. Eisenberg, B. Haber, Z. Carmel, E. Peleg, E.E. Ronat, A. Shapira, G. Vishinsky, R. Yaari, and G. Yekutieli, Phys. Rev. Letters 22, 669 (1969).

TABLE I

a)

average photon energy (GeV)	1.443 $\pm$ 0.003	2.84 $\pm$ 0.01	4.66 $\pm$ 0.01
full width at half maximum(GeV)	0.050,($\pm$ 1.8%)	0.150,($\pm$ 2.7%)	0.300,($\pm$ 3.3%)
incident electron energy(GeV)	8.13	12.0	16.0
No. of frames scanned	16,127	29,785	30,435
No. of events found	920	1,459	1,357
No. of frames used for pair count	620	1,120	926
No. of pairs counted	4,595	8,011	6,900
assumed pair production cross section (mb)	18.7	19.4	19.7

b)

topology	Number of events found for k(GeV) 1.44	2.84	4.66	corrections applied in % for k(GeV)	1.44	2.84	4.66	cross section in μb for k(GeV) 1.44	2.84	4.66
1 prong*)	356	293	200	scan eff. out of beam low **) energy	+2.5 --- -7.1	+5.1 -9.8 -14.2	+6.1 -12.5 -14.0	54.9±3.2	22.7±1.5	15.6±1.2
3 prong	536	986	877	out of beam low energy	--- -1.4	-1.0 -2.0	-0.9 -4.2	85.6±3.7	91.5±3.2	81.6±2.8
5 prong	1	96	190	low energy	---	---	-1.0	0.2±0.2	9.2±1.0	18.4±1.3
7 prong		2	8		----	----	----		0.2±0.2	0.8±0.3
with strange particle decay	27	82	82	low energy	---	-0.8	-2.8	4.4±0.9	7.7±0.9	7.8±0.9
TOTAL	920	1459	1357	scan eff out of beam low energy	+1.0 -3.6	+1.0 -2.7 -4.5	+0.9 -2.5 -5.1	145.1±5.7	131.3±4.3	124.2±3.9

*) An n-prong event has n charged particles without detected strange particle decay.

**) The low energy cut-offs were at 1.0, 2.25, and 3.0 GeV respectively.

Figure Captions

1. (a) Experimental layout of the beam.

   (b) - (d) The histograms show the pair energy spectra at 1.4, 2.8 and 4.7 GeV. The solid histograms show the energy spectra of events fitting the reaction $\gamma p \rightarrow p\pi^{+}\pi^{-}$ (168 events at 1.4 GeV, 758 events at 2.8 GeV, 293 events at 4.7 GeV). In Figs. 1c,d $p\pi^{+}\pi^{-}$ events with photon energy below 2 GeV are not shown.

2. The total hadronic photoproduction cross section as a function of the photon energy:

    from ref. 6;

    from ref. 7;

    this experiment.

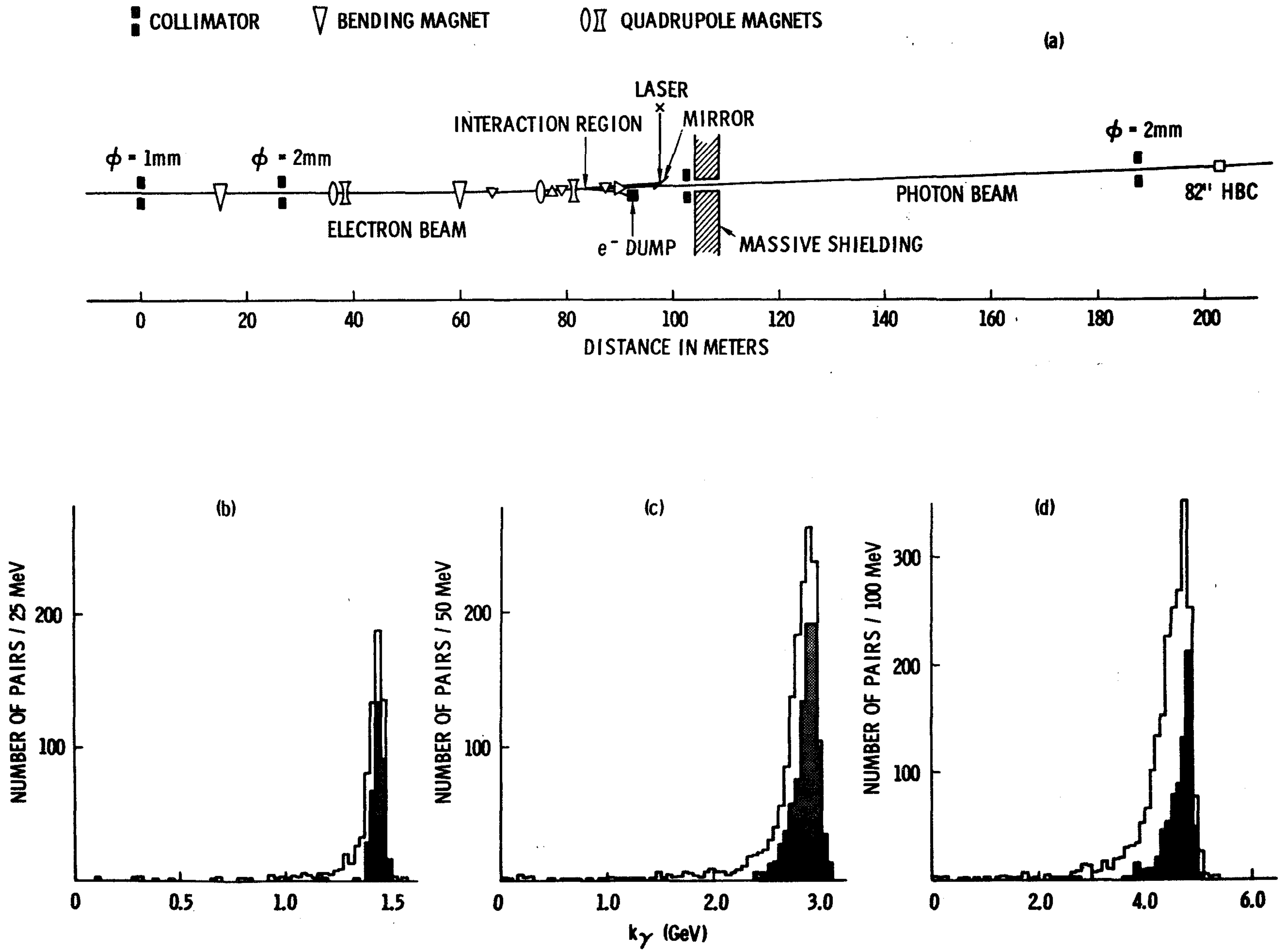
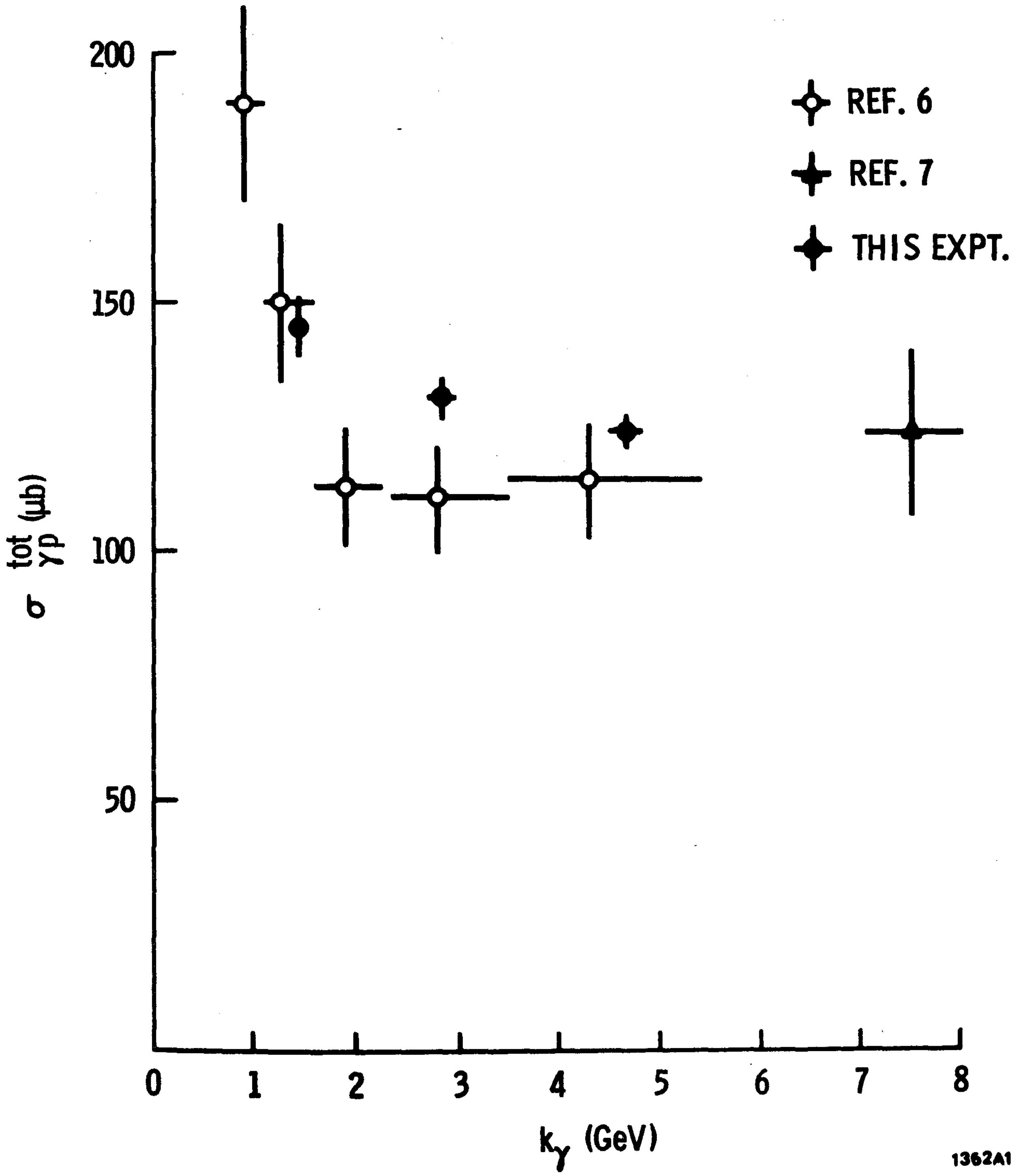

COLLIMATOR
BENDING MAGNET
QUADRUPOLE MAGNETS
(a)
LASER
INTERACTION REGION
MIRROR
ϕ = 1mm
ϕ = 2mm
ϕ = 2mm
ELECTRON BEAM
e^- DUMP
MASSIVE SHIELDING
PHOTON BEAM
82" HBC
0 20 40 60 80 100 120 140 160 180 200
DISTANCE IN METERS
(b)
NUMBER OF PAIRS / 25 MeV
0 0.5 1.0 1.5
(c)
NUMBER OF PAIRS / 50 MeV
0 1.0 2.0 3.0
k_γ (GeV)
(d)
NUMBER OF PAIRS / 100 MeV
0 2.0 4.0 6.0

Fig. 1



200
150
100
50
$\sigma^{tot}_{\gamma p}$ (μb)
REF. 6
REF. 7
THIS EXPT.
0
1
2
3
4
5
6
7
8
k_γ (GeV)
1362A1

Fig. 2